SYLLABUS
ELEC 261: ELECTRONIC MATERIALS AND QUANTUM DEVICES
FALL 2018

Credit Hours: 3

Time: 1:00–1:50 pm, MWF

Place: M. D. Anderson Biological Lab 123

Prerequisites: MATH 102 AND (PHYS 102 OR PHYS 112)

Instructor: Junichiro Kono, Professor of Electrical & Computer Engineering, Physics & Astronomy, and Materials Science & NanoEngineering, kono@rice.edu.
Office hours: 2:30–4:00 pm, Monday, 351 Brockman Hall

Graders: Natsumi Komatsu, Graduate Student, Electrical & Computer Engineering, nk31@rice.edu and Jorge Zepeda, Graduate Student, Electrical & Computer Engineering, jz48@rice.edu.

Course Assistants: Jakob Grzesik, Junior, Electrical & Computer Engineering, jmg22@rice.edu and Sahil Patel, Junior, Materials Science & NanoEngineering, srp11@rice.edu.

Course Objective: This course focuses on the classical and quantum physics behind the electrical and optical properties of materials and their fundamental role in modern electronic and optoelectronic devices. It will not only cover silicon, which is the main material used in the past and current commercial processor and memory technology, but will also highlight ongoing research on possible alternatives and novel materials.

Required Textbook: James D. Livingston, *Electronic Properties of Engineering Materials* (Wiley, 1999)

Recommended Textbooks: Safa O. Kasap, *Principles of Electronic Materials and Devices* (McGraw Hill, 2018), and Laszlo Solymar, Donald Walsh, and Richard R. A. Syms, *Electrical Properties of Materials* (Oxford, 2014)

Grading: 60% – Exams and 40% – Homework

Exams: There will be two midterm exams and one final exam. They are in-class, open-book exams. You may look at any of the following: 1) the textbook (Livingston), 2) notes you took during class sessions, and 3) problem sets + solution sets. Exams MUST be an individual effort, and any violations of this will be considered violations of the Rice Honor Code.

Homework: A problem set per week will be given, which can be downloaded before the first class each week. Homework is due at 11:59 pm on Tuesday in the following week. Late homework will be accepted until 11:59 pm on Friday in the same week as the due date with a penalty of 10% per day after they are due, that is, 10% on Wednesday, 20% on Thursday, and 30% on Friday.

Rice Honor Code: In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-systemhandbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

Disability Support Services: If you have a documented disability or other condition that may affect academic performance, you should: 1) make sure that this documentation is on file with Disability Support Services (111 Allen Center, adarice@rice.edu, x5841) to determine the accommodations you need; and 2) speak with the instructor to discuss your accommodation needs.

Course Schedule: Below is a list of modules and lessons:

Module 1: Introduction
- Lesson 1: Overview
- Lesson 2: Materials Science and Modern Technology
- Lesson 3: Diverse Experimental Techniques
- Lesson 4: Mathematical Foundations I: Complex Numbers and Partial Derivatives
- Lesson 5: Mathematical Foundations II: Vector Calculus
- Lesson 6: Mathematical Foundations III: Differential Equations

Module 2: Electrical Conduction
- Lesson 1: Early History of Metal Theory
- Lesson 2: Ohm's Law
- Lesson 3: DC Concudtivity
- Lesson 4: The Hall Effect
- Lesson 5: AC Conductivity
- Lesson 6: The Plasma Edge
- Lesson 7: Cyclotron Resonance

Module 3: Dielectric and Optical Properties
- Lesson 1: DC Polarization and Dielectric Constant

Lesson 2: AC Polarization and Dielectric Constant

Lesson 3: Optical Polarization and Refractive Index

Lesson 4: Dispersion, Attenuation, and Diffraction

Module 4: Introduction to Quantum Mechanics

Lesson 1: Early History of Quantum Mechanics

Lesson 2: Planck's Law of Black-Body Radiation

Lesson 3: Radiation as Particles – Photons

Lesson 4: Particles as Waves – de Broglie's Relationship

Lesson 5: Schrödinger's Wave Equation

Lesson 6: Quantum Tunneling

Lesson 7: Bound States and Energy Levels

Module 5: Quantum States in Atoms

Lesson 1: The Hydrogen Atom I

Lesson 2: The Hydrogen Atom II

Lesson 3: Multielectron Atoms

Module 6: Free Electron Fermi Gas

Lesson 1: Hamiltonian

Lesson 2: Density of States

Lesson 3: Electronic Heat Capacity

Lesson 4: Magnetic Susceptibility

Module 7: Electron Waves in a Crystal

Lesson 1: Nearly Free Electrons

Lesson 2: Crystal Structures

Lesson 3: Reciprocal Lattice

Lesson 4: The Bloch Theorem

Lesson 5: The Kronig-Penny Model

Lesson 6: Interatomic Bonds

Lesson 7: The Tight-Binding Method

Lesson 8: Dynamics of Bloch Electrons

Lesson 9: Effective Mass

Module 8: Semiconductors

Lesson 1: Why Semiconductors?

Lesson 2: Band Structure of Semiconductors

Lesson 3: Intrinsic and Extrinsic Semiconductors

Lesson 4: Alloys, Heterostructures, and Quantum Wells

Lesson 5: Quantum Wires and Quantum Dots

Module 9: Quantum Devices

Lesson 1: Solar Cells

Lesson 2: Quantum Cascade Lasers

Lesson 3: Carbon-Based Terahertz Device

Lesson 4: Semiconductor Spintronics

Course Learning Outcomes: Students completing the course will be able to:

(1) discuss and apply fundamental concepts and theories of solid state physics focusing on the atomic-scale physics behind the transport of electricity in materials
(2) identify, formulate, and solve scientific and engineering problems related to the electronic and optoelectronic properties of solids
(3) describe commercial processor and memory technology based on silicon and the physics behind ongoing research on possible alternatives and novel materials
(4) apply techniques, skills, and modern engineering tools necessary for practices in the field of solid state science and engineering

Detailed Course Learning Outcomes: Students completing the course will be able to:

(1) Calculate the electrical conductivity from the charge density and mobility
(2) Calculate the charge density from the Hall coefficient
(3) Calculate the plasma frequency from the charge density
(4) Calculate the effective mass from the cyclotron frequency
(5) Sketch the black-body radiation intensity as a function of frequency at a fixed temperature
(6) Calculate the wavelength of an electron or neutron moving at a fixed velocity
(7) Solve the Schrödinger equation for simple one-dimensional potentials
(8) Explain the meaning of the uncertainty principle
(9) Calculate the eigen-energy of a given quantum state in a hydrogen atom
(10) Explain how bands and band gaps arise from a tight-binding picture
(11) Explain how bands and band gaps arise from a nearly-free electron picture
(12) Sketch the Fermi-Dirac distribution for a given temperature and Fermi energy
(13) Sketch the density of states versus energy for one-, two-, and three-dimensional systems
(14) Calculate the velocity and effective mass of a Bloch electron at a given wave number

(15) State the difference between metals and insulators

(16) State the difference between intrinsic and extrinsic semiconductors

(17) Estimate the intrinsic carrier density at room temperature from the effective masses and band gap

(18) State the difference between direct-gap and indirect-gap semiconductors

Relationship of Course Outcomes to Program Outcomes: At the conclusion of ELEC 261, students should have gained (in SACS/ABET format):

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (e) an ability to identify, formulate, and solve engineering problems
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Program Outcomes Addressed	Tests & Assignments That Demonstrate This Outcome
(a)	HW1–HW5, Midterms
(e)	HW1–HW5, Midterms
(k)	HW1–HW5, Midterms

Syllabus Change Policy: This syllabus is only a guide for the course and is subject to change with advanced notice.